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Original Article

FORCED CONVECTION AND PRESSURE DROP OF CUO-TIO NANO-PARTICLE-FLUID INSIDE MINUS SLOPE MICROFIN PIPE UNDER CONSTANT WALL TEMPERATURE

FARHAD HEKMATIPOUR[1], MILAD JALALI[2] & FARZAD HEKMATIPOUR[3]

[1]*Department of Energy and Environment, Science and Research Branch, Islamic Azad University, Tehran, Iran*

[2]*Faculty of Physics, Semnan University, Sokkan Park, Semnan, Iran*

[3]*Farzad Hekmatipour is with the School of Mechanical Engineering, College of Engineering, Islamic Azad University Kashan Branch, Kashan, Iran*

ABSTRACT

In this article, empirical analysis of the effects of forced convection and Darcy friction factorise done using nano-fluid and downward flow in negative incline tube. This can be affected by boundary condition when the flow regime was fully developed and laminar, and wall temperature was isothermal. The use of nano-fluid, negative slope can have effect on the augmentation of forced convection. Two equations have been strongly suggested to be estimate the forced convection and pressure drop in a downward flow. The peaked deflection of isothermal and Darcy friction factor are 20% and 21% respectively. The results show that the use of equation is appropriate as long as these are used in experimental investigation. In addition forced convection ratio with ratio of pressure drop is calculated. As long as the rise of figure of merit is more than a unit, It is no longer suitable to apply CuO-TO nano-fluid, minus slopes and micro fine pipe. The maximum FOM is 1.59% extracted with 1.5% weight fraction and slope of 60ºat Prandtl number of 310. The upshots illustrate majority of the quantities is more than a unit, and as a consequences the heat transfer improvement is more than rise of pressure drop.

KEYWORDS: Finned Pipe, Pressure Drop, Convection, Downward Flow & Nano-Particle

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Nomenclature

Cp	Specific heat capacity $(kJ/kg.K)$
D_h	Hydraulics Diameter (m)
f	Darcy friction factor $(\pi^2\rho D^5\Delta P)/\ 2L\dot{m}^2$
Gz	Graetz number (Re Pr D/L)
h	Convection coefficient $(W/m^2.K)$
K	Thermal conductivity $(W/m.K)$
ṁ	Mass flow rate (kg/s)
N	Number of fin
Nu	Nusselt number $(\bar{h}/k)$
Pr	Prandtl number $(\mu Cp/k)$
$\dot{Q}$	Flowrate (m^3/s)
Re	Reynolds number $(\rho uD/\mu)$
T	Temperature (K)
ΔP	Pressure drop (Pa)
U	Uncertainty (%)
z	The height of fin (m)
Greek Symbols	
ϑ	Dynamic viscosity (m^2/s)
η	Figure of merit

ρ	Density (kg/m^3)
$\Delta\rho$	Density difference (kg/m^3)
Π	Number of Pi
γ	Helix angle (º)
θ	Inclination of tubes (º)
τ	Vertex angle (º)
φ	Nano-particles mass concentration (%)
Ω	Pumping Power (W)
Subscripts	
b	Characteristics of fluid at average bulk temperature
b_f	Base fluid
$\mathrm{b,o}$	Bulk outlet
$\mathrm{b,i}$	Bulk inlet
exp	Experimental values
$\mathrm{n_f}$	Nanofluid
w	Appraised at the wall conditions

INTRODUCTION

Enhancement of convective heat transfer can be effective on the reduction of heat and fuel waste in manufactural usages such as microelectronics, heat exchangers, air conditioning, etc. It is valuable to employ new methods because the energy efficiency is valuable in industrial usages. A method, which is more beneficial than others, is using nano-particles because studies exposed that thermal conductivity of fluids augments with the rise in weight fraction [1-5].

The result of investigation demonstrates that the applications of nano-particle-fluids are lucrative because, the heat transfer improvement is greater than ordinary fluids like water [6-10]. Another reason why nanofluids are better than classical fluids is because of the slight augmentation of the friction factor in pipes [11-14]. Some investigations focus on mixing several methods of improving forced convection since impressive augmentation of heat transfer is achieved under different conditions [15-19]. For instance, several studies are performed to show the effect of applying nano-particle-fluid and mechanical method on convection and pressure drop. Some studies use nanofluid and mechanical methods such as microfin tube [20, 21, 22], twisted tape and wire insert into tubes [23-26], annulus tubes [27, 28], mini-channel [29, 30] and helical tubes [31, 32]. Although the result of using microfin tube and nanofluid shows that heat transfer increase substantially, when the Darcy friction factor does not augment significantly. Therefore, using microfin tube and nanofluid is highly to be beneficial in industrial usages. There is a reason why finned tubes can be effective on heat transfer enhancement, creating vortex flow and declines the boundary layer [20]. Thus, it is eligible to increase the forced convection. However, it is necessary to conduct more research on improving heat transfer and increment of pressure in microfin tube. This is because new correlations were introduced to predict the behaviour of nanofluid in microfin tube under several conditions.

Initially, several researches were conducted to analyse the effectiveness of nanofluid and classical ways on mixed convection, forced convection and Darcy friction factor in horizontal and vertical pipes. Due to the difficulty in providing is thermal condition in comparison with heat flux, most researchers use heat flux. Thirdly, a few researches focus on the improvement of heat transfer by using microfin tube and nanofluids. Another reason is lack of understanding the effect of negative inclination pipe and nanofluid in round and microfin tube on forced convection enhancement and the increment of Darcy friction factor. In this experiment we tried to determine the effects of negative inclination and CuO-TO nanofluid on forced convection and Darcy friction factor in microfin tube. Boundary conditions are isothermal tube and fully hydraulically developed in this article.

EMPIRICAL APPARATUS

Properties of Nanofluid

Experiments show that the half-value scale of copper oxide nano-particles and *sincerity* are 40 nm and 99%, respectively. SEM picture of copper oxide nano-particles is shown in Figure 1. Irregular shapes are seen in Figure 1. An ultrasonic UPS400 tool with frequency of 24 kHz and the power of 400 were used to survey a consubstantial and a comparative stable nanofluid. Preparing three suspensions of CuO-TO nano-particles-fluid with the weight fraction of 0.5%, 1%, and 1.5% is done employing a precise module. The nano-particle-fluid is stable for 216 hr, and precipitation of nano-particles begins from 216 hr and exists exactly for 14 days. Thermo-physical properties of the CuO-TO nanofluids are demonstrated in Table 1 and Table 2, respectively. The rheological properties of nano-particle-fluids measurement are brought forward by Akhavan-Behabadi et al. [33].

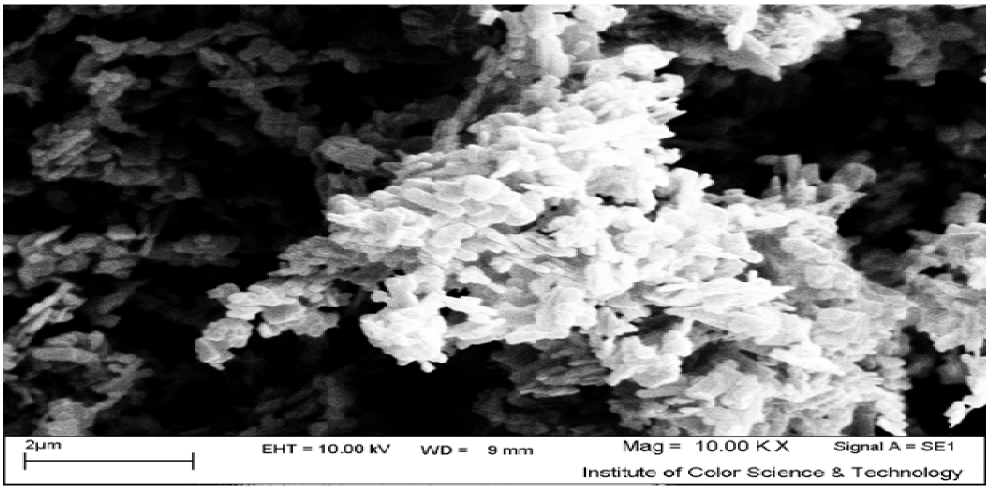

Figure 1: SEM Picture of the CuO Nano-Particles.

Table 1: Rheological Properties of Thermal Oil

Rheological Properties	Temperature (°C)	
	38	100
ρ (kg/m^3)	855	815
Cp$(kJ/kg.K)$	2.03	2.30
$\vartheta(m^2/s)$	32×10^{-6}	5.2×10^{-6}
k (W/m. K)	0.133	0.128
Prandtl number	395	76

Table 2: Rheological Properties of CuO Nano-Particles

Rheological Properties	Quantity
Morphology	Irregular shapes
Particle measurement (nm)	40
Sincerity (%)	99
Bulk density (kg/m^3)	790
True density(kg/m^3)	6400
SSA (m^2/g)	20
Thermal conductivity $(W/m.K)$	20

Experimental Device

Due to the menstruation of convective heat transfer and Darcy friction factor of nano-particle-fluids, the assemblage of experimental device is constructed as bring forwarded analogically in Figure 2. The Turning flow has several parts such as test section, pre-cooler, storage tank, heat exchanger, gear pump, flow meter, differential manometer, thermocouples, flow control system. The characteristics of pipes and CuO-TO fluids are utilised in experimental analysis which have been depicted in Table 3 and Table 4. Aslope of smooth and finned tubes are applied of who's characteristic are bestowed in Table 3. The duration which has a steady state-flow in test tube is 16 minutes and the duration wanted for setting down empirical information is 30 minutes.

Venue of test section was in vapour pool sustained at bulwark temperature of 98ºC. The glass-fibre insulation is applied to detract the heat losses from vapour pool in a couple of stages.

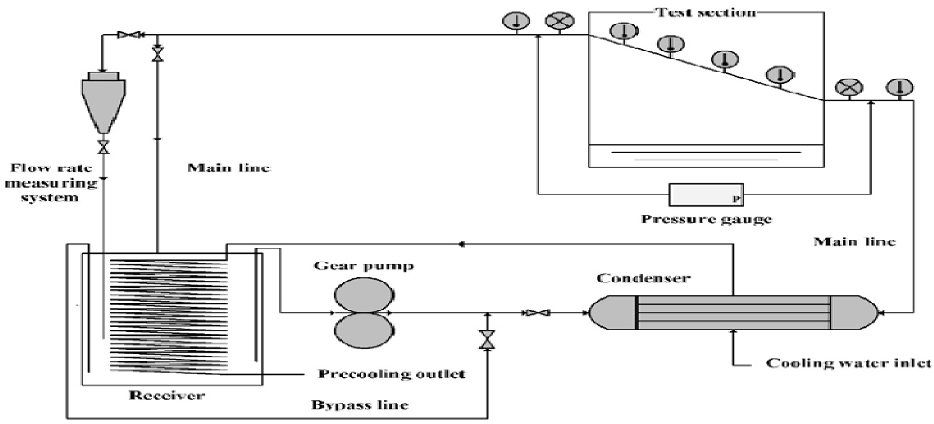

Figure 2: Schematic of the Test Setup.

Table 3: Characteristics of the Smooth and Finned Tubes

Parameter	Girth Smooth Tube	Girth Finned Tube
Pipe inner/outer diameter (mm)	8.95/9.52	8.62/9.52
Pipe length (mm)	500	500
Pipe thickness (mm)	0.42	0.45
Fin height (z) (mm)	---	0.2
Fin pitch (mm)	---	0.45
Number of fins (N)	---	60
Helix angle (γ)	---	18
Vertex angle (τ)	---	24

Table 4: The Rating of CuO-TO Flow

Segment	Quantity
Diameter/Length	0.01784
Gz	1130 to 3610
Pr_{n_f}	300 to 390
Re	196 to 790
Wall Temperature(ºC)	98
Thermal conductivity $(\mathrm{W/m.K})$	0.132 to 0.154
Heat Capacity$(\mathrm{kJ/kg.K})$	1.569 to 2.08

Table 5: Specification of the Tools

Characteristics	Tools	Ratio	Precision
inner/outer temperature	RTD PT 100	-200 to 400°C	±0.1°C
Pipe wall temprature	K-type thermcouple	-200 to 999°C	±0.1°C
Flow rate	Separation funnel	0 to 11	±100 ml
Pressure drop	PMD-75	10 mbar to 40 bar	±0.075

Tables are considered to cool nano-particle-fluids. Primarily, chilled water passes from helical coil and considerable vapour pool was utilised to drop the temperature of nano-particle-fluids. Due to the drop in temperature of nano-particle-fluid flow, the shell and tube heat exchanger was employed to arrive at 15ºC. Using gear pump, really cool nanofluid in storage tank is circulated throughout the main line. The gear pump provides constant velocity. Because of regulating and changing the volumetric flow rate in circulating line, a bypass line is designed to return back a part of flow rate to reserve tank. Therefore, it is possible to change the flow rate during experiments. A globe valve is also applied to transfer a part of flow rate to reserve tank, so that the flow rate is changed into empirical facility. The volumetric flow rate was even in the laminar regime. On the test tube, four thermo-couples were vulcanized at distinctive spacing to maintain the tube wall temperature. To measure the inlet and outlet temperature of nanofluid in experimental facility, a couple of thermocouples was fixed and coordinated at the inlet and outlet of the test tube.

Instruments

Measuring the nanofluid temperature in the test sections inlet and outlet was accomplished by using two RTD PT 100 fixed to thermometers applying with precision of ±0.1°C. Assembling of RTD sensors used in particular to perceive the mid-point of nanofluid temperature is done by knowing the inlet and outlet temperature. Location of four K-type thermocouples with the SU-105 KPR sensor is done at 100mm spacesT_1 (10 Cm), T_2 (20 Cm), T_3 (30 Cm), and T4 (40 Cm) since sensors read the temperature of wall pipes.

The thermocouples are vulcanized on the outer wall tubes to avoid the impacts of vapour and nano-particle-fluid on thermocouples. The primary investigations illustrate that, because of rare thermal resistance of smooth and finned tubes wall contrasted to convective one, the temperature gradient in the pipe wall is insignificant. The temperature of T_1, T_2, T_3 and T_4 are 98.1, 97.8, 98.0, and 98.1 respectively, which illustrates the wall temperature of tube was relatively stable.

Measuring the pressure drop is done by applying a PMD-75 pressure transmitter with precision of ±0.075%. Utilising a 1000 ml graduated funnel gauges the volumetric flow rate. Measuring volumetric flow rate is done by knowing the funnel filling time and employing a chronometer with the precision of 0.01s.

Measuring analytic error of forced convection and Darcy friction factor is done based on way of examining an empirical upshots [34, 35] and it is obtain by applying the information in Table 5. As a consequence, the peaked deflection of the forced convection, the Nusselt number and figure of merit are6.2%, and 6.5%, respectively.

RESULTS AND DISCUSSIONS

The assessment of forced convection of nano-particle-fluid flow and Darcy friction factorise conducted, and given below:

$$Nu_{exp}=\frac{\dot{m}C_p}{\pi Lk}\ln\left(\frac{T_w-T_{b,i}}{T_w-T_{b,o}}\right) \tag{1}$$

$$f_{exp}=\frac{\pi^2\rho D^5}{2L\dot{m}^2}\Delta P \tag{2}$$

Thecalculation of the microfin hydraulic diameter tube is done [36]:

$$D_h = \frac{2R}{\left(\left(\frac{Nh}{\pi}\right)+1\right)} \tag{3}$$

Since the peak deflection of experiments with classical equation is obtained in smooth tube, a contrast with upshots of experiments and predictableSider-Tate and Baeher and Stephan [37]and Hagen-Poiseuile [32] equations, respectively is done. Figure 3 displays the comparisonwith experimental information and auspicated numerical equations. Comparing experimental information with the auspicatedequations of forced convection and Darcy friction factor is approximately 13% and 11%, respectively. The deflection of experimental information and old equations aresuitable. The peaked deflection of empirical information which is less than 21% of old empirical equations, as a consequences the outcome isreputable [27-30]. Emperical outcomeis used for divination of experimental investigation .

Darcy Friction Factor

Defining the hydraulic developing length can have an importanteffecton flow regime andflowshape, and this developing length is achieved with$L_e < 0.058 Re_d d$. The maximumhydraulicdeveloping length was0.38m. Demonstrating experimental information and drawing diagram were performed applying Excel and SPSS software in this article. In Figure 4. It exposes the Darcy friction factor ratio of nanofluid flow in a negative slop microfin tube. The Darcy friction factor increase with the augmentation of weight mass fraction and Graetz number.

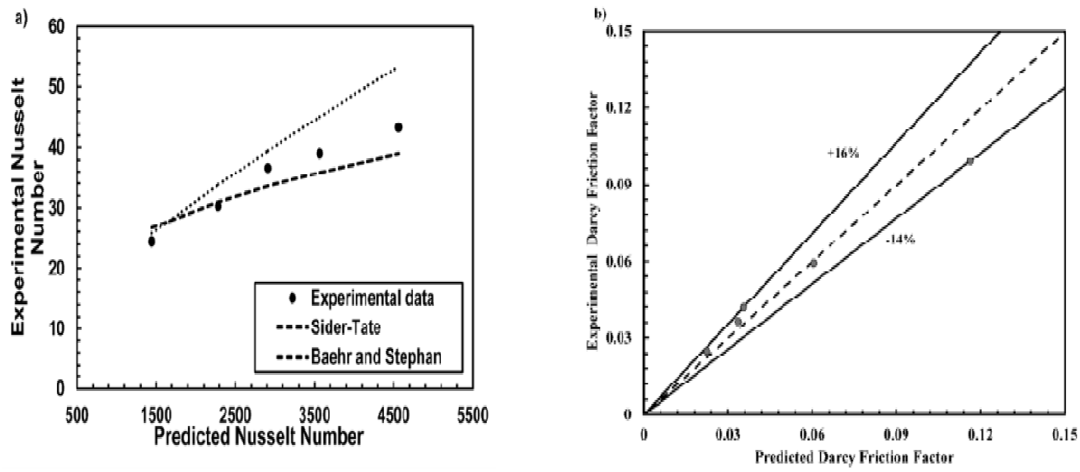

Figure 3: Contrast of the Empirical Information with the Old Models: (a) Darcy Friction Factor; (b) Nusselt Number.

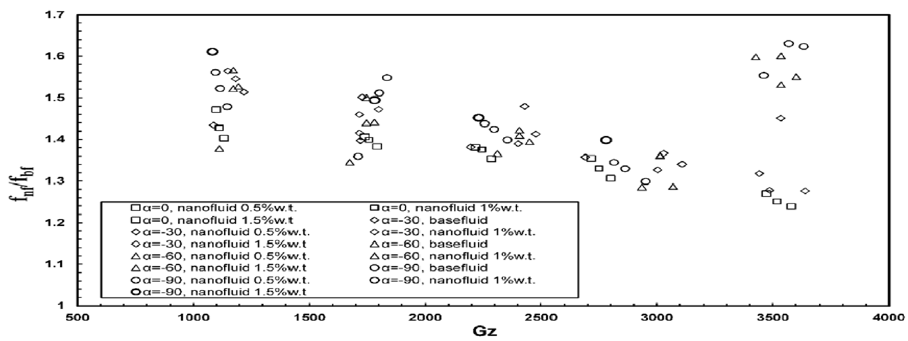

Figure 4: The Use of Nanofluid Affect on Augmenting Darcy Friction Factor in Negative Inclination Angle in Microfin Tubes.

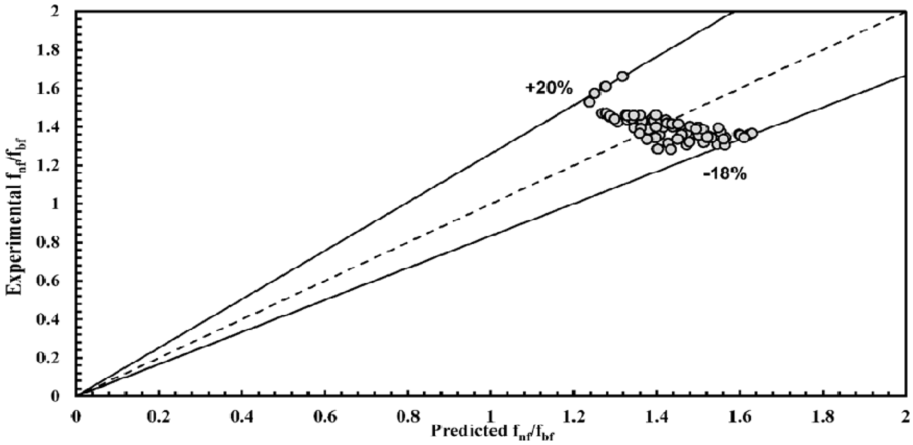

Figure 5: Contrast of the Empirical Darcy Friction Factor of the Nano-particle-Fluid Flow with the Forecasting of Equation 4 in Inclined Finned Tube (α=0, -30, -60, -90).

The Darcy firction factor increases with the augmentation of weight fraction and Reynolds number in microfin tube. The declination of the boundary layer occurs due to making Brownian motion and vortex flow in minus inclined finned pipe. Distinguishable reason is the surge of the speed profile and share wall stress. It is comfirmable with scientific experiments to explain the enhancement of Prantl number as a factor impacting on the augmentation of weight fraction. Thus, the Darcy friction factor increases to arriveat approximately 15%. Classical equations are not eligible to assess the Darcy friction factor of nanofluid in minus slope microfin. Based on the empirical data, a correlation is suggested to assign the effectiveness of applying nano-particle-fluid and minusslope on the Darcy friction factor in microfin pipe. The prognostic able correlation is exposed to prognosticatethe Darcy friction factor of CuO-TO flow. This follows as:

$$\frac{f_{n_f}}{f_{b_f}} = 0.56\,(1+\cos\theta)^{0.1}\,(1+\varphi)^{0.5}(1+(GZ)^{0.1})^{0.5}\left(\frac{\mu_{n_f}}{\mu_{b_f}}\right)^{0.14} \tag{4}$$

The correlation accredits for$0 < \varphi < 1.5\%$, $-270 < \theta < 0$, $196 < Re < 790$, 300$< Pr_{nf} < 390$, $1130 < Gz < 3610$. The utilisation of negative slope, nano-particle weight fraction, Graetz number, dynamic viscosity rate is obtained by the Darcy friction factor of CuO –TO nano-particle-fluid. The contrast between the upshots of experiments with estimated quantity is being indicated in Figure 5. The perceived maximum deflection of experimental information is approximately 20%. So that introducing correlation is capable to prognosticate the upshots of Darcy friction factor. This is lucrative correlation because bulk effects like nano-particles mass concentrations; Graetz number, negative slope, and dynamic viscosity were applied in this correlation. However, utilising old correlations will be general in various investigations, and the classical correlations were not capable to estimate the impacts of nano-particle-fluid and minus slope in micro-fin pipes. Thus, this is significant to define a correlation in downward flow in the slope micro-fin pipe.

Nusselt Number

Calculating thermally developing length of nano-particle-fluid flow was obligatory to define the status of flow in microfin pipe. Calculation is done by applying thermally developing length$L_e < 0.058RePr$. The minimal thermally developing length is 42.40m. Excel and SPSS software are used for painting the upshots of empirical information gained with empirical apparatus. However, this is vouch able using nano-particle-fluid flow. Microfin is influential on forced convection, and negative inclination angle, solid -liquid and microfin tube which can be beneficial on heat transfer

improvement. Figure 5 indicated the maximum Nusselt number in weight fraction is as 1.5%, at a slope of -30, and Reynolds number is 780. Figure 6 indicates the effectiveness of employing copper oxide nano-particles and finned pipe on forced Convection of nano-particle-fluid flow in downward flow in slope tubes. Mutating inclination and Brownian motion effects flow shape or it is because of making vortex flow. It results in diminishing boundary flow in downward flow in slope tubes. Utilising experimental information, a Correlation is defined to evaluate the impacts of nano-particle-fluid flow, minus inclined forced convection in slope pipes, is as followed:

$$Nu = 0.45\,(1+\cos\theta)^{0.1}\,(1+\varphi)^{0.1}(1+(GzPr)^{0.68})^{0.46}\left(\frac{\mu_{n_f}}{\mu_{b_f}}\right)^{0.14} \tag{5}$$

The correlation accredits for$0 < \varphi < 1.5\%$, $-270 < \theta < 0$, $196 < Re < 790$, 300< $Pr_{nf} < 390$, $1130 < Gz < 3610$. Comparing with the experimental upshots with anticipated Eq. (5) is indicated in Figure 7. The peaked aberration from the experimental information was 21%. The error of an equation is permissive. Thus, it can be used for assessment of forced convection in downward flow in inclined tubes.

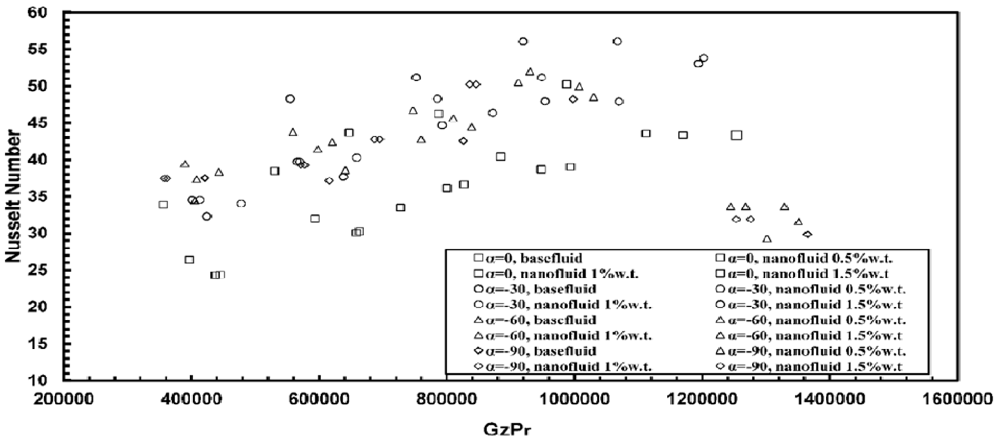

Figure 6: The Impact of Using Nanofluid on the Nusselt number in Downward Flow in Inclined Finned Tubes.

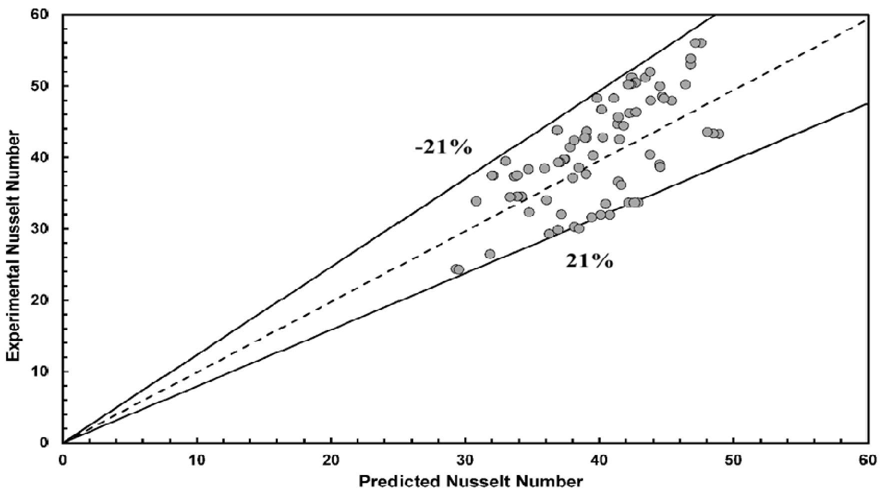

Figure 7: Comparison of the Empirical forced Convection of the Nano-Particle-Fluid Flow with the Evaluation of Equation 5.

The forced convection with the rise in pressure drop is obtained by determining effect of the augmentation of forced convection and pumping power the FOM which is given by [38, 39]:

$$FOM = \frac{h_{n_f}/h_{b_f}}{(\Omega_{n_f}/\Omega_{b_f})^{(1/3)}} \quad (6)$$

The figure of merit is defined by the determination of experimental information which is allowable as advised in manufactural usages. Figure of merit is described as the forced convection rate over experimental pumping power. The impact of nano-particle-fluid flow and negative gradient finned pipes on forced convection and pumping power is described in the same time. As long as figure of merit is more than a unit, the impacts of nano-particle-fluids, minus slope and finned pipe will be useful. Fig. 8 shows that the compound of nano-particle-fluid, finned tube and minus slope enhance the forced convection is1.58, and it's obtained weight mass fraction is1.5%, and slopeis330. This perceptible, altering of the Darcy friction factor of nano-particle-fluid flow in downward flow in microfin tube is considered marginal as the specialty of CuO is its anti-friction property. Friction drops because of altering mode of friction from the sliding mode to rolling mode. Thus effectiveness of drum is introduced [40].

FOM

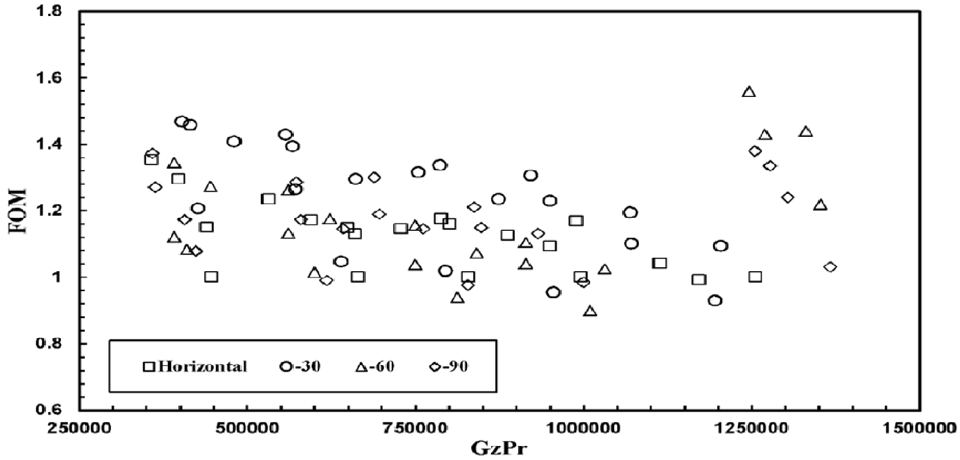

Figure 8: The FOM of the nanofluid Flow According to the Equation 6.

CONCLUSIONS

Using nanofluid on forced convection and Darcy friction factor, can dramatically affect in negative slope microfin tube. The range of weight mass fraction and negative slope changes from 0% to 1.5% and from 270 to 360, respectively. Resulting experiment in a downward flow slope pipe indicates forced convection and Darcy friction factor surge by rise of the weight fraction of 0% to 1.5%, Prandtl numbers range from 300 to 390 and Graetz number range from 1130to 3610. Correlations were introduced to examine the effect of nano-particle-fluid isothermal wall and downward flow on forced convection and Darcy friction factor in slope microfin pipe. Resulting correlations were agreeable because of maximum deflection of empirical upshots. Maximum divergence is less than 21%rising forced convection and Darcy friction factor by decreasing boundary layer, augmenting stable speed and Brownian motion. Making vortex flow and sharing wall stress were caused by Brownian motion. Therefore, forced convection rand Darcy friction factor is increased by applying nano-particle-fluid and downward flow in the slope of microfin pipe.

Experiments were conducted by applying nano-particle-fluid and minus slope in manufactural uses, accompanied by forced convection ratio with an increase in pumping power. The results of calculations show the use of nano-fluid, negative slopes and microfin tube have positive effects on heat transfer when the pumping powers rise slightly.

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AUTHOR PROFILE

MiladJalali, I graduated from NODET(National Organization for Developing Exceptional Talents) high school in Iran. Due to my interest about sky and astronomy, I chose physics as my university major. I took my bachlor degree from Shahrood University of technology in major of physics. My main interest is quantum mechanics. I continued my study in master and I worked on plasma physics. I graduated from Semnan University(Iran) then I pursue my Ph.D degree in condensed matter physics in Nanjing Southeast University in China. My research interest is Spintronics and nano physics and I am a Ph.D student now. I published different type of papers in several journals such as Indian Journal of Science and Technology, Journal of Thermal Analysis and Calorimetry, Heat and Mass Transfer. I worked on the enhancement of the convective heat transfer and pressure drop with nanofluid in different boundary conditions, the simulation of net-zero energy building in different weather condition, and experimental and numerical optimization of steam load in power plant and heat exchangers. I like to be optimized energy consumption in building and energy consumption in power plant. During my studies I won some prizes like Iranian astronomy contest and physics national contest and young innovators etc.

Farhad Hekmatipour, I am a Master degree in Energy Engineering-Technology Energy from IAU Science and Research Branch in 2013 and Bachelor degree in Heating and Airconditioning facilities from Tarbiat Dabier Shaid Rajee in 2008. I have published more than 12 papers in different international Journals such as Applied Thermal Engineering, Journal of Thermal Analysis and Calorimetry, Heat and Mass Transfer, Experimental Thermal Fluid and Sciences, International Journal in Communication in Heat and Mass, Casse Study in Heat and Mass Transfer, Indian Journal of Science and Technology, Global Journal of Engineering and others. I have particiated in different type of internationa conference like International Conference on Heat Transfer and Fluid Mechanic in Dubai and International Conference on Fluid Flow, Heat and Mass Transfer in Los Angles in 2018.I worked on the enhancement of the convective heat transfer and pressure drop with nanofluid in different boundary conditions, the simulation of net-zero energy building in different weather condition, and experimental and numerical optimization of steam load in power plant and heat exchangers. I am member of Publons, Research gate, Elsevier reviewer, Iran nanotechnology innovation council(INIC) and Power Engineering Magazine. I achieved award for publishing papers in international Journals around world from Iran nanotechnology innovation council(INIC).

Farzad Hekmatipour, I graduated from Islamic Azad University Kashan branch in Mechanical Engineering- Fluid Mechanic in Iran. Due to my interest about heating, aircondintoning, ventilation and cooling. I work as manager in different company but my field is designing pharmacitucal manfacture in Iran. In addition, I do experimental and numerical research on optimiztion of energy consumption in power plant and building. My interest works on net-zero energy building in my courntry. I published different type of papers in several journals such as Indian Journal of Science and Technology, Journal of Thermal Analysis and Calorimetry, Heat and Mass Transfer , andInternational Research Journal of Applied and Basic Sciences. I worked on the enhancement of the convective heat transfer and pressure drop with nanofluid in different boundary conditions, the simulation of net-zero energy building in different weather condition, and experimental and numerical optimization of steam load in power plant and heat exchangers. I like to be optimized energy consumption in building and energy consumption in power plant.I have particiated in different type of internationa conference like International and national Conference on Heat Transfer and Fluid Mechanic in Dubai and national e-conference on Advance in Basic Sciences and Engineering.